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Computerized Assessment of Individual Differences

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This research was sponsored by the Cognitive Science Program, Office of Naval Research, under Grant No. N00014-86-C-0065, Contract Authority Identification No. NR4422538.

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92-18426

92 7 1 151

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	8/29/91	Final 10/1/87 to 1/30/91

4. TITLE AND SUBTITLE

Computerized Assessment of Individual Differences

5. FUNDING NUMBERS

C N00014-86-C-0065

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 N Quincy St.
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NR4422538

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Co-ordinating ability is the ability to integrate information from several domains in order to accomplish a single task. An example is integrating verbal instructions with visual perception of scenes. We have found that co-ordinating ability in linguistic and perceptual tasks is an ability that is over and above the ability to deal with linguistic or perceptual tasks alone. A related study analyzed orienting ability, i.e. the ability to locate oneself in large-scale space. Orienting requires the integration of information from a succession of visual scenes. This ability was shown to depend upon the ability to form and unite "surveyor's representations" of different scenes, given the information in a ground plane view. Orienting ability was studied by contrasting the abilities of college students (novices) and sports orienteers, including international competitors.

14. SUBJECT TERMS

Intelligence, Attention: Dual Tasks.
Visual-spatial Reasoning, Intelligence.
Individual Differences.

15. NUMBER OF PAGES

34

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	

Computer Based Assessment of Cognitive Abilities: Final Report

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1. Introduction

This is the final report for Contract N00014-86-C-0065. The contract involved research on cognitive abilities to be conducted by a joint University of Washington and University of California, Santa Barbara team, with the University of Washington serving as the prime contractor. This report will describe the chief scientific findings by both groups. The location of work will be indicated when specific references are made.

The research dealt with two topics; both related to the co-ordination of information from several sources. The major purpose of the project was to uncover the existence (or determine the non-existence) of a generalized ability to co-ordinate information received from two distinct sources, e.g. co-ordination of visual information with verbal directions about the visual scene. To take a colloquial example, this is what a taxicab driver has to do if a passenger gives directions when the driver is in an unfamiliar neighborhood. As the example indicates, we concentrated on the co-ordination of information in situations in which very rapid responding was required, i.e. tasks that had to be completed within one or two seconds at most. Our specific goals were to determine whether the ability to co-ordinate information from different sources was distinct from the ability to deal with each source independently, to develop methods of measuring such an ability if it existed, and to develop a model for the co-ordination task itself. Our work concentrated on co-ordination of perceptual and verbal information, because so many situations require this sort of co-ordination. However we shall make some comments about other types of information co-ordination.

A second goal of our studies, approved in a separate memorandum after the research was initiated, was to examine the sort of information co-ordination needed in a particular task; ground navigation. We will refer to this as *orientation ability*, where orientation should be understood as keeping track of one's location while moving in large space. Orientation is of interest because it depends upon co-ordinating perceptual information received over time, as one obtains different views of the local environment. The goal of this part of our study was to determine whether or not good navigators had special visual capabilities, or whether they relied upon spatial reasoning and visual memory.

Specific studies have been reported separately, either in the literature (see section on bibliography) or in quarterly reports. Therefore this report will summarize the major scientific findings, but will not report any one study in great detail.

This report describes scientific findings only. The University of Washington Grants and Contracts office will submit separate administrative and financial reports, as required.

2. Research on co-ordination ability

2.1 Introduction to the problem

In a co-ordination task a person must integrate information from two separate sources in order to determine an appropriate response. The easiest example to understand, and the one that we shall deal with most, involves the integration of verbal and perceptual information. Questions like "Is that Mary Jones crossing the street?" or "Do you hear the nightingales singing? " are co-ordination tasks. So is the co-ordination task in which a flight instructor tells a student pilot what he or she is supposed to do as the student attempts a first landing.

The question that interests us is "Are some people particularly good at co-ordinating information, over and above their ability to deal with information received over a single channel. In the examples just given, for instance, performance clearly depends upon the ability to comprehend language and to make a perceptual judgement. We will call these component tasks. Can performance on the combined task of, say, recognizing (a) that you are asked about Mary Jones and (b) that that the woman crossing the street is NOT Mary Jones be predicted from knowledge of the ability to understand English and to recognize people *and nothing else* ? If the answer to this question is "yes" then there is no need to postulate the existence of an information co-ordination ability. If the answer is "no," there must be individual differences in co-ordination of perceptual and verbal information that are apart from individual differences in dealing with perceptual and verbal information by themselves.

In order to test these ideas we devised a number of tasks that require co-ordination ability. The basic idea can be illustrated with our Arrival Time task, which is illustrated in Figure 1. In this task a participant sees two "ships" (actually, elliptical shapes) moving toward different targets, possibly at different speeds. At some point (indicated by the dotted line on the figure, but not actually shown in the display) the ships disappear from the screen. The screen also displays a question about the ships.[1] This question might be linguistically simple (as in "Will the black ship arrive before the white ship?") or complex (as in "Will the white ship not arrive after the black ship?") The question could always be answered "Yes" or "No." In practice, participants responded by striking a "yes key" or a "no key" on a conventional keyboard.

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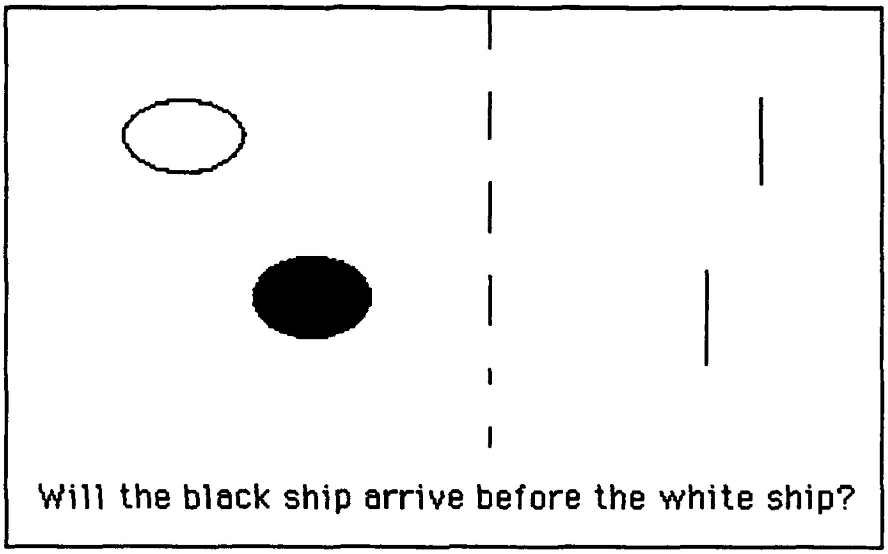
1. In control experiments we have contrasted situations where the message is displayed in text to situations in which the message is spoken. This change makes no difference to the results, so we have used displayed text for ease of programming.



A Race Task. Two objects "race" from left to right across the screen, towards the vertical bars on the right. At the same time a question appears on the screen, as shown. Before the participant can answer the question the objects reach the dotted line and disapper from view. The question is answered by depressing keys on a computer keyboard. Both accuracy and reaction time are recorded.

Figure 1 . A Race task

This artificial task has all the necessary elements of a co-ordinating task. The participant must comprehend a sentence and simultaneously make a perceptual discrimination related to the question asked in the sentence. The basic perceptual-verbal distinction can also be extended to other perceptual tasks. For instance, in some of our studies we have used an auditory discrimination task, where a person listens to repetitions of high and low pitched "beeps." The task is to determine which stream of beeps is being presented at a faster rate.

These co-ordinating tasks can easily be altered to present a component task in which individual differences in performance are determined by the ability to deal just one of the "channels" of information. This is done by making one of the component tasks trivially easy. For instance, in the Arrival Time Difference task (Figure 1) the perceptual component can be made easy by having the faster object be closer to its target when the objects disappear from view. This produces a very easy visual-perceptual problem. The only real problem, from the participant's point of view, is determining the meaning of a complex sentence like "Will the white ship arrive not before the black ship?". (People do become confused, and there are systematic individual differences in their degree of confusion.)

Alternatively, the ability to deal with the perceptual problem alone can be measured by presenting hard perceptual problems. where the *slower* ship is ahead when they disappear from the screen. This combined with a very simple question, such as "White ship first?" Performance in this task will be determined by visual-perceptual ability rather than verbal ability.

Given our measurement procedures, what sort of statistical analyses can be used to determine whether or not a co-ordinating ability exists? We have used a regression technique that is itself of some interest.

First, suppose that no co-ordinating ability existed; i.e. that performance on a co-ordinating task was determined solely by performance on the two component tasks. In that case performance on the co-ordinating task should be predictable from performance on the two combined tasks. In the case of the Arrival Time Difference task, for instance, a regression equation could be formed from

(1) Verbal task Performance + Perceptual task Performance = Co-ordinating task performance + error of measurement.

Statistically, if equation (1) holds precisely all individual differences in co-ordinating task performance should be predictable from individual differences on the verbal and perceptual tasks, *after allowing for unreliability in all measures*. Failure to observe this relationship indicates the possible existence of a co-ordinating ability.

It is hard to make a stronger argument from failure of equation (1) as a predictor of performance in the co-ordinating task, simply because we do not feel comfortable arguing for the existence of something, based upon a failure to account for variance. This brings us to our second, and most important, statistical model.

Suppose that a co-ordinating ability does exist, independent of ability to do the component tasks. In particular, the model that we consider is for variances. It says that the variance in the co-ordinating task can be described as

(2) Variance in Co-ordinating task = Variance in Visual-Perceptual task + Variance in Verbal Task + Variance in Co-ordinating ability + Error Variance. [2]

We may also consider the partial variance in the co-ordinating task conditional upon statistical removal of the effects of each component task. Logically, this is the residual variable

(3) Residual = Co-ordinating task performance - Predicted performance based upon component task performances.

If equation (1) is correct the residual will be the effect of measurement instability. If equation (2) is correct, the residual will include a measurement instability error and, in addition, a term reflecting an individual's ability to co-ordinate information from several sources.

We use this fact to develop the statistical model shown in Figure 2. Component and co-ordinating task performances are measured on two separate occasions. We then correlate the residuals (i.e. equation 3, after some statistical manipulations) on each occasion. If a co-ordinating ability does not exist the residuals should be uncorrelated, because measurement stability, by

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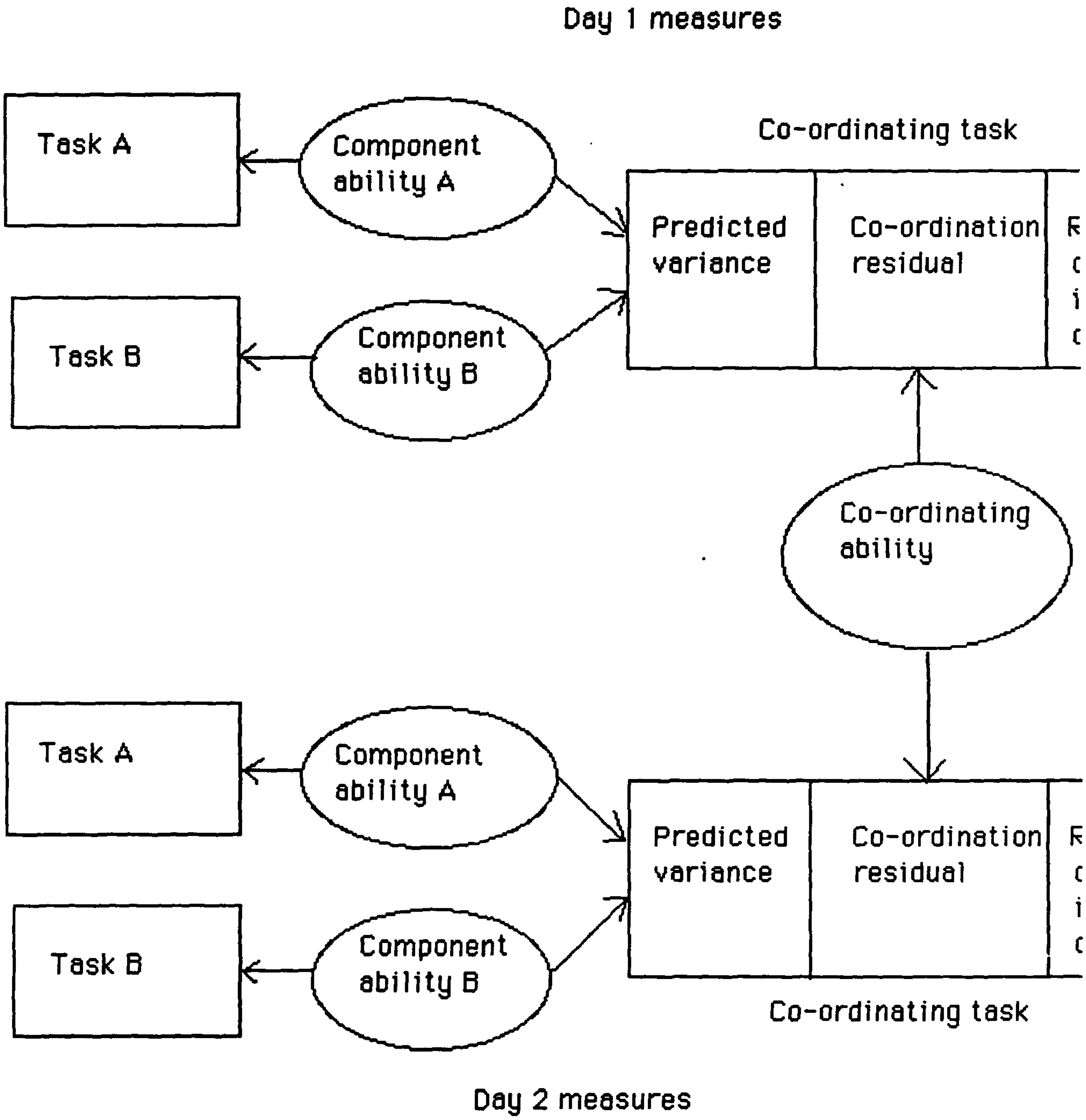
2. In practice we also have to consider covariance terms. The statistical techniques used allow for this problem. It is not discussed here for simplicity of presentation.



A statistical model for testing for co-ordination ability. People perform component tasks A and B and a co-ordinating task requiring integration of the two component tasks. The experiment is replicated on two separate days. If a co-ordinating abilities exist the residual variance in the co-ordinating task (i.e. that variation not predicted by component tasks A and B) should be correlated across days.

Figure 2: A statistical model for measuring co-ordination ability

definition, is uncorrelated over occasions. If a co-ordinating ability does exist, however, the residual variance on each occasion will include residual variance associated with co-ordinating ability. Therefore there should be a positive correlation between residual variances.

2.2 Basic Findings on Co-Ordination Ability.

Several experiments were conducted applying the statistical model described to the Arrival Time Difference task and to its auditory analogue. Most of the work was carried out by the UW group, after consultation with all investigators. This work is described in detail in Yee, Hunt, & Pellegrino (in press). Summaries of some of the earlier studies were also reported in an invited chapter by Pellegrino, Hunt, & Yee (1989). The main result is simple; co-ordinating abilities do exist. In several experiments we found correlations between the residuals of co-ordinating task performance. The correlations were on the order of .5, across all tasks. Perhaps most important, there was a reliable, albeit slightly lower (.3) correlation between the residuals for visual-verbal tasks and for auditory-verbal tasks. This indicates that there is a generalized ability to co-ordinate perceptual and verbally presented information.

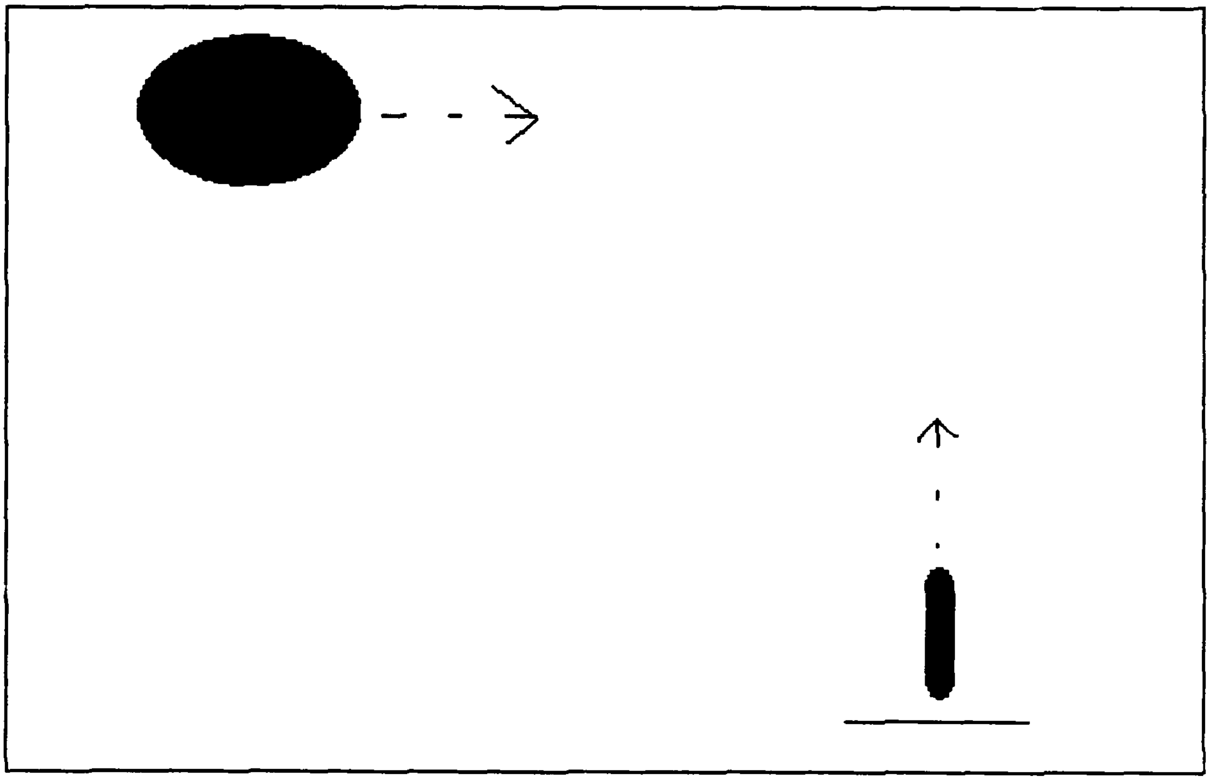
The UCSB group confirmed these results independently , using a slightly different statistical model based on the LISREL analysis of covariance technique (Morrin, 1990; Morrin, Law, & Pellegrino, 1990).

2.3 Related findings.

Two extensions of these findings have been developed. The UW group's tasks involved co-ordination of separate streams of information across two major perceptual domains; visual-spatial and verbal information. A series of studies by the UCSB group applied basically the same logic to study co-ordination ability within the visual-spatial domain.

The UCSB group concentrated upon the study of dynamic visual-spatial tasks. In these tasks individuals must reason about the motion of objects in their visual fields. The ATD task described earlier is an example of one such task, but there are others. Dynamic visual-spatial tasks are important because of their ubiquity in the world. For instance, when a pedestrian attempts to cross a busy intersection adequate dynamic visual-spatial reasoning is literally a matter of life and death.

In particular, we have studied a variety of tasks called *intercept* tasks. One is shown in Figure 3. Here the task is to "launch a missile" to intercept the object moving across the screen. The missile travels at a constant speed. Therefore the observer must project target movement forward in order to decide when to launch.



In an intercept task the object travels from left to right across the screen. When the participant presses a button on a keyboard the "missile" rises at a constant rate. The task is to "launch the missile" so that it will intercept the object. Perceptual and motor co-ordination are required.

Figure 3: An intercept task.

The UCSB group pointed out that dynamic visual-spatial reasoning in both intercept and arrival time tasks requires integration about target location and target speed. This means that, logically at least, a co-ordination ability can operate entirely within the visual-spatial domain. Using statistical procedures similar to those used by Yee et al. (in press) for uncovering across-domain co-ordination, the UCSB group demonstrated the existence of a within-domain ability for co-ordination of location and speed information (Law, 1990; Morrin, 1990; Morrin, Law, and Pellegrino, 1990).

In a further analysis by the UCSB group we found that failures of dynamic visual-spatial reasoning are usually due to over-reliance on distance information, without adequate consideration of speed. For instance, in the arrival time task the commonest error is to fail to realize that a fast moving, trailing object is going to "catch up" to a slow moving, leading object. Good dynamic visual-spatial reasoners do incorporate speed and distance information, while poorer reasoners react to distance information alone (Fischer, 1990; Hickey, 1990; Law, 1990).

In previously reported research we had found that women generally do less well than men in dynamic visual-spatial tasks. (As in any group comparison, there are exceptions.) A preliminary study by the UCSB group suggests that this is because women generally are not as accurate in judgements of speed as men are. Men and women are equally accurate in judging distances (Law, Pellegrino, & Hunt, 1990).

Finally, what if one moves away from the integration of perceptual and verbal input information, to examine the relationship between the analysis of perceptual input and the computation of motor outputs? Would evidence for a perceptual-motor co-ordination ability be obtained?

Somewhat surprisingly, the answer turns out to be "no." Yee, Laden, and Hunt (1991) conducted a series of experiments in which intercept tasks were combined with relatively difficult motor output tasks. Performance in the combined task could be predicted from performance in visual-spatial perceptual tasks and motor tasks, alone.

This result at first may seem somewhat counterintuitive, since colloquial wisdom tells us that there are people who are good at "hand-eye co-ordination." We do not dispute this. Our results indicate that such individuals have, in a sense, "good hands" and "good eyes," separately. We need not postulate an independent ability to co-ordinate the two. This contrasts with the integration of perceptual and verbal information, where co-ordination does have to be considered.

2.4 Theoretical Analysis:

Yee, Hunt, and Pellegrino (in press) developed a theoretical model that summarizes many of these effect. In order to understand the motivation for the model a finding not related to individual differences needs to be explained.

In virtually every experiment that we have conducted on perceptual-verbal co-ordination we have observed what we call *compression effects*. We now describe these effects.

Consider some idealized perceptual task, which is presented at difficulty levels P1 and P2, where P1 < P2. By definition, this means that performance in condition P1 is worse than performance in P2. For simplicity, consider the case of reaction time. The difference in difficulty between levels P1 and P2 can be measured by the difference in reaction time. Letting R(Px) be the reaction time under condition Px, the effect of the P1-P2 contrast is measured by

(4) $E(P1-P2) = R(P2) - R(P1).$

Now suppose that the perceptual task is presented as part of a co-ordinating task involving verbal information. Let R(Px,Vy) be the reaction time measure for a task at perceptual level of difficulty Px and verbal level of difficulty Vy. (Also, assume that V1, V2 etc. represent increasing levels of verbal difficulty.) The P1-P2 effect on reaction time, in the presence of verbal difficulty level Vy, can be written

(5) $E(P1,Vy-P2,Vy) = R(P2,Vy) - R(P1,Vy).$

For consistency of notation, we will use P0 and V0 to indicate those conditions in which there is a negligible perceptual or verbal component. Thus (4) would be rewritten

(6) $E(P1,V0-P2,V0) = R(P2,V0) - R(P1,V0).$

A *perceptual compression effect* occurs when the P1-P2 contrast is reduced in the presence of increased verbal difficulty. By definition, this means that

(7) $E(P1,Vy-P2,Vy) > E(P1,Vz-P2,Vz)$ if $z > y$.

Note that (7) is defined in terms of differences. Thus it would be possible for performance on the perceptual task to deteriorate, absolutely in the presence of the verbal task, while the differences in performance between two levels of perceptual difficulty decreased. Figure 4 shows this for the idealized case of reaction time, where poor performance is associated with long reaction times.

An analogous set of definitions apply to verbal compression effects. All that needs to be done is to interchange the V and P terms in equations 5-7.

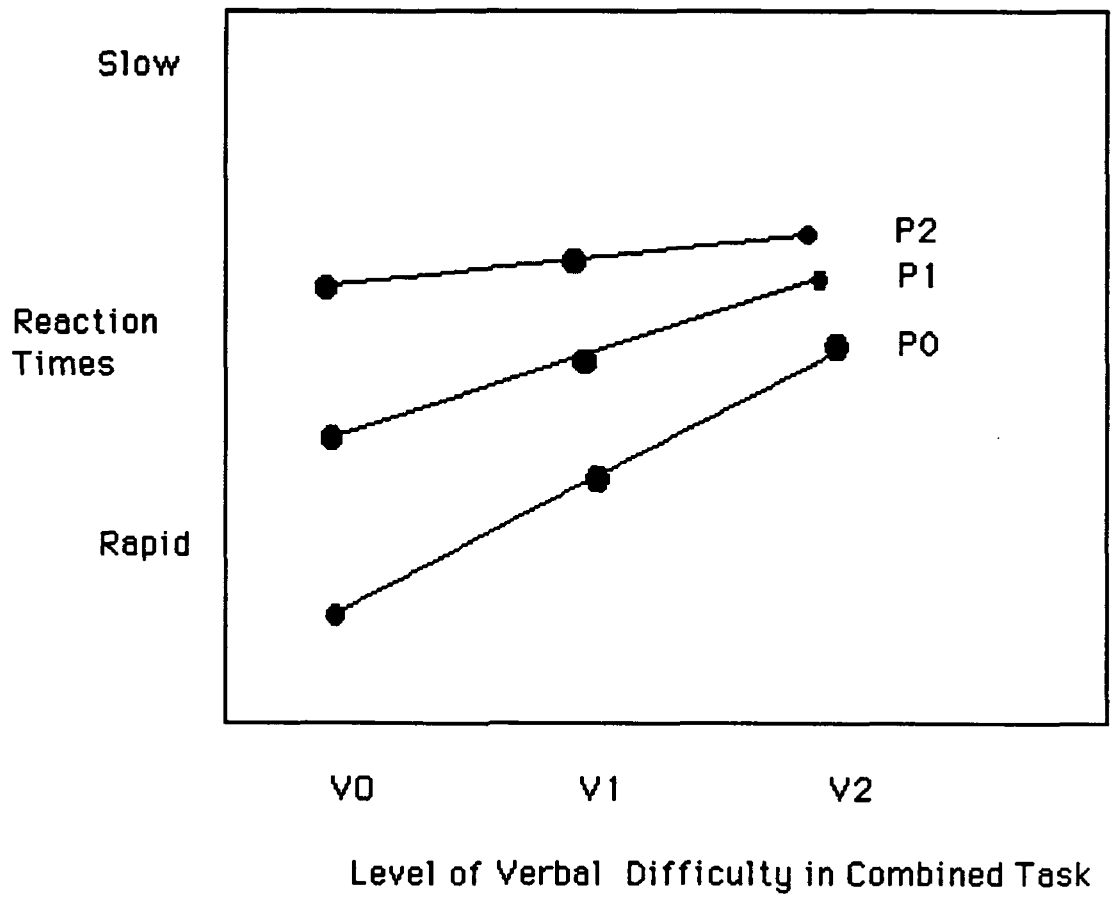
We have obtained both verbal and compression effects in virtually every experiment where we also obtain evidence for a co-ordinating ability. In addition, we do not obtain evidence for compression effects unless we also obtain an effect associated with the co-ordination of verbal and perceptual information. This result is not dictated by statistical considerations. Compression effects are defined in terms of changes in mean performance, across individuals, while co-ordination ability is defined by analysis of the variance-covariance matrices for measures obtained under different conditions.

Yee et al. (in press) point out that compression effects rule out every model that assumes that co-ordination depends upon drawing upon a unitary attentional resource. On the other hand, compression effects can be explained by the following two stage model for processing within each domain of information reception.

1. A purely within-domain process analyzes either perceptual or verbal information into a domain-specific representation.

2. The domain-specific representation is translated into an internal, common representation that makes possible the comparison of information obtained from either the perceptual or verbal domains.

Stage 1 proceeds independently for the perceptual and verbal domains. Conflicts can occur in Stage 2, unless the perceptual (or verbal) domain information has been translated prior to the inception of translation of information from the other domain. Co-ordination abilities refer to the efficiency with which such conflicts are handled.



The Compression Effect. The difference between three perceptual tasks of progressively increasing difficulty (P0, P1, and P2) decreases as the tasks are combined with progressively more difficult verbal tasks (V0, V1, and V2)

Figure 4: The Compression Effect

The formal mathematical argument behind the Yee et al. model is complicated, and would be too detailed to present in this report. We point out that the model depends only upon the assumption that performance is monotonically related to difficulty level within a domain, and that performance in one domain is not facilitated by the presence of information processing in another domain. The model does not depend upon any assumption of linearity between internal conceptualizations of "difficulty of information processing" and external measures, such as reaction time or probability of error.

The results obtained from the different studies we have conducted indicate that the Yee et al. model applies whenever a person must co-ordinate perceptual and verbal information. On the other hand, the model does not apply to the co-ordination of perceptual input and motor output. Neither does it apply when the situation involves co-ordinating purely perceptual information, such as the co-ordination of speed and distance to determine arrival times. Our observations, collectively, suggest the model shown in Figure 5. The model can be described in words as follows:

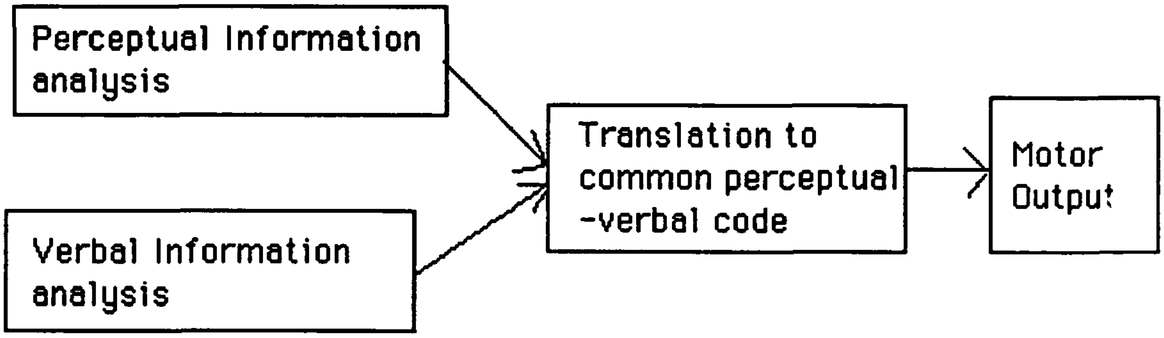
1) Information arrives on verbal and a variety of perceptual channels. Percepts and verbal information are determined independently.

2) The verbal information and the perceptual information are co-ordinated, by being merged into a common amodal internal language. Fodor's term "the language of thought" is appropriate for this representation. The translation process from a perceptual or verbal representation into an internal language represents a bottleneck. Translations from perceptual representations interfere with simultaneous translations from verbal representations and vice-versa.

3) The internal representation is used to compute signals to a motor output unit.

4) Logically, perceptual monitoring is required to control motor output. The extent to which such monitoring involves the internal representation process is not known. This is indicated by the "?" on the perceptual-motor feedback loop in Figure 5.

We suggest that this model can be used to analyze a great many situations in which people are required to co-ordinate perceptual and linguistic information in order to control a motor output. Since such tasks are ubiquitous in an industrial world the model may have considerable practical interest.



In the Yee-Hunt-Pellegrino model perceptual and verbal information analysis occurs independently and in parallel. Following the analysis the results are translated into a common, amodal internal code. Interference can occur if perceptual and verbal information must be translated at the same time. Motor output occurs after translation and is independent of perceptual and verbal information analysis. Co-ordination ability depends upon the effeciency of the transfer process.

Figure 5: A Model of the stages in a co-ordination task.

3.0 Locating oneself in space.

3.1 Overview

This part of the report describes the results of a series of experiments conducted by the UW group on a particular type of information co-ordination task; locating oneself in "large space." An example is the ability to be aware of the direction of objects not in the field of view. More general, orientation ability is the ability to locate oneself in a very large space and to determine paths from point to point in that space. Although all humans have to develop this ability to some extent, previous research (outside of this project) has shown that there are very wide individual differences in orientation ability. Good orienteers are generally believed to represent the space about them in a "surveyor's form," which they build up from piece by piece experience with particular paths. At the other end of the spectrum of orientation ability, there are some people who do not ever seem to develop a surveyor's representation of the spaces in which they live. Instead they seem to memorize step-by-step paths from one key location to another.

Building a surveyor's representation is an information integration task, where the integration takes place over time. For instance, the author of this report can draw a fairly accurate map of his place of work, the University of Washington from memory, yet he has never experienced all of the University in a single visual field. Psychologically, though, the sort of integration involved is very different from the sort of integration studied in the experiments reported in section 2. There we were concerned with integrating information across channels defined by logical dimensions, e.g. speech vs. non-speech. Here we are concerned with integrating perceptual information in distinct presentations, separated by a fairly long time.

Anyone who wishes to study orientation ability faces a major practical problem. Measuring individual competence in orientation is an expensive proposition. The ultimate test, of course, is to let people explore a novel environment and then test them for their knowledge of it. This can involve hours of work to obtain a small number of data points from a single person, and is simply not practical. In order to avoid this problem our studies took a more practical course. We used an "expert-novice" design, in which we contrasted the information processing abilities of everyday individuals to those of competitive sports orienteers.

Our experts were sports orienteers. Orienteering is a competitive sport, in which the participants must race from checkpoint to checkpoint, through unfamiliar terrain. Unlike cross country runners, orienteers choose their own routes, based on very rapid analyses of maps and terrain. A complete course may be anywhere from six to twelve kilometers long. In the upper competitive levels of the sport the course is intentionally laid across confusing terrain.

With the co-operation of the United States and International Orienteering Federations, we tested orienteers ranging from local competitors to international team members at world cup events . Our control groups were introductory psychology students and cartography students. The introductory students were chosen because they constitute psychology's standard reference population. The cartography students were chosen because they had evidenced an interested in spatial reasoning, as an abstraction, but had not displayed special skills in reasoning about their own location.

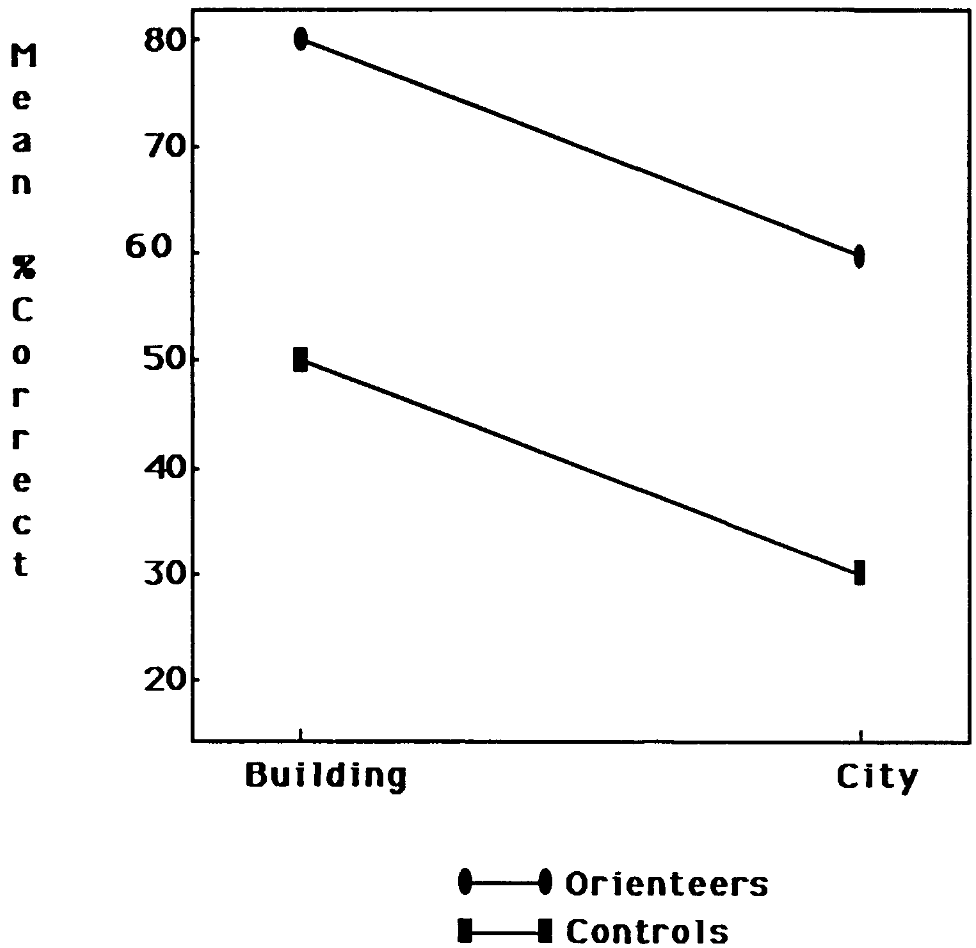
The first question to be asked in any expert-novice study is whether the experts have some generalized ability or whether they have developed a set of domain-specific skills. In particular, do sports orienteers excel at locating themselves in general, or have they developed domain-specific, less interesting skills for dealing with the particular types of courses used in competitive orienteering? To answer this question we tested orienteers on spatial-tasks that were progressively less like orienteering itself. To foreshadow, we found that the orienteers indeed had a general ability to locate themselves in space. Next we considered a process model of how orienteering might occur. We then conducted measures of key processes in that model, to see where individual differences contribute to success. Finally, we determined whether or not orienteering ability, as defined by our expert-novice contrast, was related to the abilities measured in standard psychometric tests of visual-spatial ability. This is a non-trivial question, because all the psychometric tests ask examinees to perform spatial reasoning tasks in "small space" i.e. objects which can be viewed in a single visual field. Psychologists have asserted that these tasks are related. In fact there is a small space psychometric test called orientation. A literature search indicated that there are very few validation studies, probably because of the difficulty of obtaining valid measures of individual orienteering ability.

Before proceeding, a word is in order about our expert groups. We will distinguish two levels of expertise. The term "orienteer" will be used to refer to competitors in local and regional meets. "Elite orienteer" will refer to members of national teams, who compete in international events.

3.2 Is orienteering a general ability?

Sports orienteering meets are usually conducted in woodlands or rolling hill country. In order to test orienteers' ability to locate themselves in the environment, in general, we compared sports orienteers to undergraduates in an exercise in locating oneself in an indoors environment.

Orienteers and students toured one floor of the University of Washington Psychology Building. This building has a fairly unusual design, which can best be described as an inner "core" building surrounded by an outer building. Thirty minutes after the tour ended, participants were placed in a windowless experimental booth on the same floor and asked to indicate the direction from their current position to the areas they had previously been shown and, to commonly known areas beyond the walls of the building. Figure 6 shows that the orienteers clearly outperformed the undergraduates. This established the generality of the expert-novice distinction.



Frequency of correct location of target directions from a point in the interior of a building. Points shown were either in the building itself or were prominent landmarks in the surrounding city.

Figure 6: Accuracy of location in an exercise in indoor orienteering

3.3 Steps in Developing a Survey Representation of the Environment.

In order to develop a surveyor's representation of a space an observer must observe relevant information in a visual scene, remember it, infer the bird's eye view of the scene in front of the observer from the information contained in the view in their own plane, connect such views of different scenes in order to develop a picture of a space that is too vast to ever be perceived from a single vantage point. Which of these processes can account for individual differences in orienting skill?

Our first test was of perception and coding of scenes. Orienteers and control subjects briefly observed a complex visual picture, that is best described as a cartoon sketch of a scene at a busy street corner. The sketch was drawn realistically, rather than using the schematics typical of "bugs bunny" style cartoons. The observer was then asked to recall information from the picture.

Each item of information to be recalled was classified as being either critical or extraneous to orientation. Critical information is information that could be used to construct a stable surveyor's representation. Generally, this means geographically permanent structures, such as the location of the bakery on the corner. This sort of item will be called a Critical landmark item. By comparison, the child running into the street and the red car passing are extraneous to navigation.

We found that orienteers in general do extract more information from a visual scene than do novices. What is more interesting, though, is that their advantage is greatest for critical landmark information. Interestingly, this skill appears to be continuous throughout ranges of orienteering expertise. Sports orienteers exceed psychology students in their ability to extract visual information from a scene, even though our psychology students were, in general, younger than the orienteers and would be expected to show somewhat better visual memory on that basis alone. Sensitivity to landmark information extends throughout ranges of orienteering. Elite orienteers remember more critical information from a scene than do orienteers in general.

These results could indicate that orienteers either have a generally superior visual memory, and have learned to pay special attention to landmark information, or that orienteers have developed special skills for looking at scenes. The latter appears to be the case. We tested orienteers and control subjects in a task in which the "scene" was a random arrangement of objects, rather like a jumbled desk, instead of a geographic scene. Orienteers and psychology students performed equivalently. Our results, as a whole, indicate that orienteers are more efficient than non-orienteers in looking at geographic scenes. Presumably this is an acquired skill, and could be taught.

We next looked at the question of inferring a "bird's eye" view from a ground level view of a scene. There are two aspects of this activity; inferring the bird's eye view of a single scene and assembling the bird's eye view from several scenes into a coherent surveyor's representation of a large scale space.

To evaluate spatial inference we asked people to develop a representation of a mythical village. The "village" was constructed from architect's models, and actually fit onto a table. Slide photographs of the village were taken from "street level" perspectives. Observer's were shown the slides. Subjectively, this is equivalent to walking along the streets of the village itself, except that the observer does not actually move. Each slide showed two building at a time, although different sections of the village might consist of two, three, or four buildings.

After viewing one, two, or three scenes covering a section of the village observers were shown possible surveyor's representations, i.e. bits of the village as it could be seen from above. Some of these representations were consistent with the scenes and some were not. The observer's task was to select the correct surveyor's representation.

The task was very difficult. Undergraduate students performance was generally at chance. Orienteers also claimed that they would perform at chance, but in fact they did not. In particular, elite orienteers outperformed sports orienteers. The lowest scoring elite orienteer outperformed 50% of the sport's orienteers.

Building a survey representation of the environment is essentially an exercise in imagery. Are orienteers are superior at imagery in general, when the task has nothing to do with large space representation? To test this we adapted a task developed by S. Pinker and his colleagues. Subjects were asked to construct mental images of figures from a series of verbal instructions and then to compare them to images constructed by the experimenter. None of the figures were remotely related to navigation. For instance, one of the images to be constructed was a Valentine Heart.

The orienteers showed absolutely no advantage over controls. This was true both of sports orienteers and an elite group, members of the U.S. National Team.

We conclude from our visual inferencing studies that Orienteers are superior builders of mental representations of real world terrain, including "terrains" inside a building and "terrains" they know only from pictorial stimuli. While this may be considered an example of "far transfer" of skills, they do not show the same advantage in the construction of images from a non-navigational domain i.e.. a domain completely outside their expertise, as represented in the imaging task. We suspect that what distinguishes orienteers from others is their ability to make inferences about real-world scenes. We do not know the extent to which this is teachable.

3.4 Psychometric Testing.

We have compared orienteers to controls on standard psychometric tests of visual-spatial ability. Advocates of "situated cognition" studies have argued that standard intelligence test measures do not correlate with mental abilities exhibited in the subject's normal problem solving situations (e.g. Ceci & Likert, 1988). This is not what we find, at all.

One of the most frequently studied tests in the psychometric and cognitive literature is the mental rotation task. Although it has been argued that tasks of this type are of limited use in understanding real-world spatial functioning mental rotation is frequently considered a basic information processing function that we have to have in order to execute more complex tasks. Orienteers were superior to non-orienteers in both two and three-dimensional spatial rotation tasks. This is an important result, as spatial rotation tests require the mental manipulation of a "small-space" image that is not remotely related to orienteering itself.

In one of our studies we tested cartography students as well as orienteers and introductory psychology students. The cartography students results were intermediate between those of the orienteers and that psychology students. This is further evidence that psychometric tests of mental rotation are not paradigm-bound measures.

We found an even more striking relationship between another psychometric test and Orienteering performance. The Guilford-Zimmerman Spatial Orientation test is an example of a "small-space" task that requires perspective taking. Subjects are asked to imagine that they are looking over the prow of the boat inthe top picture of each set. They must then decide how the boat has moved to attain its angle and position in the second picture. A similar task, using views from an airplane cockpit, has been used from time to time to screen candidates for aviation training.

This task distinguishes Orienteers from trail followers and even picks out an elite group of international orienteers from other orienteers. This is not a trivial finding. The Guilford-Zimmerman task involves reasoning about a very small picture, on a desk in front of the examinee. Performance in this small-space task is, nonetheless, clearly related to performance in larger space.

3.5 Conclusions:

We believe that our results justify the following conclusions concerning orienteering.

Orienteering skill is not limited to being able to get around in the woods. It seems to be an ability to build up abstract spatial models of large-space from superior observation of salient visual cues: familiarity with the particular type of cue is not necessary. Neither are the cues provided by one's own motion.

On the other hand the ability does not extend to a general observation advantage nor to the construction of any image. Orienteers do not demonstrate an advantage in imagery that depends upon non-spatial cues.

There is certainly clear evidence for a relationship between large space and small space skills. While psychometrics have endured some attack lately, ecological validity is not an issue in this instance. People who can get around well in large-scale space do have superior spatial-visual skills, as tested by standard psychometric instruments.

On the other hand, there are a number of questions that remain to be resolved.

The most important of these questions concerns the role of training. To what extent is orientation ability inherent, and to what extent can it be trained? We suspect that the training may require literally years of experience, so laboratory studies are not feasible. It may be possible to design studies of the development of orienteering ability during, say, flight training or training for sports orienteering. In both cases, however, it is likely that candidates will have already exercised considerable self selection.

We are also interested in the question of the relation between ground navigation and navigation using artifacts, e.g. cars and airplanes. The relationship between ground navigation and navigation abilities associated with aviation are particularly interesting, because the visual scenes experienced by, say, a pilot and a sports orienteer, are very different. Nevertheless, would orienteering ability generalize between the two fields? We suspect that it might, insofar as orienteering ability is associated with a general ability to make visual-spatial inferences.

Any discussion of spatial-visual reasoning is bound to raise a question about male-female differences. Age differences are also of interest. However these questions are extremely complex. In our research we have tested both male and female orienteers. The result reported here do not interact with male-female differences. We do not believe that our design is appropriate for contrasting the performance of men and women. Orienteers, like most other groups formed by any method other than explicit randomization, are self selected. For instance, elite orienteers must both be good at locating themselves and extremely fast runners. (Some are also elite marathon competitors.) It may be that the relative contributions of speed and orientation to competitive status are different for men and women. At the local level, orienteers are often recruited to the sport because a family member is interested. We have met several women who began orienteering because their spouse was interested, but we have never met a man who made a similar report. We point out that these self-selection factors are true of, and in our opinion a weakness of, many other studies in which conclusions are drawn about "men" and "women" on the basis of sampling from a population in which the selection processes for men and women may be different.

4. Summary: General Conclusions and Further Questions.

Our investigation of co-ordinating tasks has shown that the task of co-ordinating information input along two different dimensions requires an ability that is separate from the ability to deal with information along each of the dimensions, separately. The effect is particularly strong for the co-ordination of perceptual and linguistic information. This, alone, is an important finding because of the ubiquity of tasks that involve co-ordination of perceptual and linguistic information. Co-ordination ability is less pronounced when it comes to co-ordinating two different sources of information along purely perceptual dimensions; e.g. co-ordinating speed and location information in order to predict the relative arrival times of visual objects. Nevertheless, co-ordination does occur, and requires its own special ability.

With respect to orientation, we have shown that individual differences in the ability to locate oneself on the ground depends largely upon the ability to (a) develop 'Birdseye views' of scenes from ground-level views and (b) the ability to integrate several such views into a surveyor's representation of the surrounding space. These appear to be general abilities, in the sense that they can be demonstrated in such radically different terrains as woodlands and the interior of a building.

In both the cases listed above we have developed methods for measuring the abilities described. Our measurement techniques, with some refinements, could be used in personnel selection programs.

While our research has adequately addressed the questions it set out to address, several further questions remain. One obvious one is whether the ability to integrate symbolic (linguistic) information with simultaneously presented perceptual information, as studied in our experiments on co-ordinating tasks, is related to the ability to integrate linguistic and possibly symbolic (map) information presented over time, as in the orienteering studies. The experiment required to answer this question is straightforward; ask orienteers of varying ability to participate in a co-ordinating task experiment. Unfortunately, such a study would be logistically difficult to arrange.

We have not systematically explored the role of training in either co-ordinating tasks or orienteering tasks. The issue is not whether good performance can be achieved by training; we know it can. After all, car drivers and orienteers are trained, all the time, outside of the psychology laboratory. The issue is to what extent learning to co-ordinate information generalizes. We would not conceptualize this as an issue in testing "near transfer vs. far transfer." We think this is a somewhat naive distinction between test tasks that appear to be like the the training tasks and tasks that appear to be less similar. Rather, we believe that the transfer issue should be explored by developing a dimensional analysis of the transfer and training tasks (e.g. tasks in which linguistic input is altered vs. tasks in which perceptual input is altered), and then determining the extent to which training generalizes along each dimension. A substantial experimental program would be needed to conduct such an analysis.

Our final suggestion for future research has to do with co-ordination. We have evaluated co-ordination under extremely high time pressures, where responses are typically made within two seconds or less. Orienteering involves the integration of a special type of perceptual information, presented of a period of minutes. In many command and control situations (e.g. air traffic control, military combat information centers) information is received from perceptual and linguistic sources, but the integration takes place over minutes. To what extent are these tasks like the co-ordination tasks that we have studied? Would performance in our laboratory co-ordination tasks, which can be measured within an hour, predict performance in command and control situations, where measurement presumes days or even weeks of training? We hope to do further research to address this question.

5. List of publications and major presentations.

Manuscripts, Reports, & Papers

Fischer, S. C. Factors governing performance in a visual interception task. Proceedings of the Human Factors Society 34th Annual Meeting, 929-933.

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Yee, P. L. & Hunt, E. (in press). Diluted Stroop effects: Further tests of the attention capture hypothesis. Journal of Experimental Psychology: Human Perception and Performance.

Manuscripts written, submitted or privately circulated

Law, D. . Resource allocation, strategies, and dynamic spatial tasks: Relative speed, distance, and arrival time judgments.

Law, D., Pellegrino, J. W., & Hunt, E. . An analysis of gender differences and the role of experience in relative speed and distance judgments.

Law, D., Pellegrino, J. W., Mitchell, S., Fischer, S., McDonald, T. P., & Hunt, E. Dynamic spatial reasoning and information coordination: Factors governing performance in a two-object arrival time task.

Morrin, K. A., Law, D., & Pellegrino, J. W. An evaluation of individual differences in within and across domain information coordination.

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Presentations

Yee, P. L. & Hunt, E. (1987, November). Individual differences in managing simultaneous activities. Paper presented at the Twenty-eighth annual meeting of the Psychonomic Society, Seattle, WA.

Hunt, E. (1988, March). The futures market in testing. First annual Weschler Conference on Intelligence. University of Texas, Austin.

Hunt, E. (1988, August). Cognitive science and measurement: Implications and problems. International Congress on Intelligence sponsored by the Australian Council for Educational Research, Melbourne, Australia.

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